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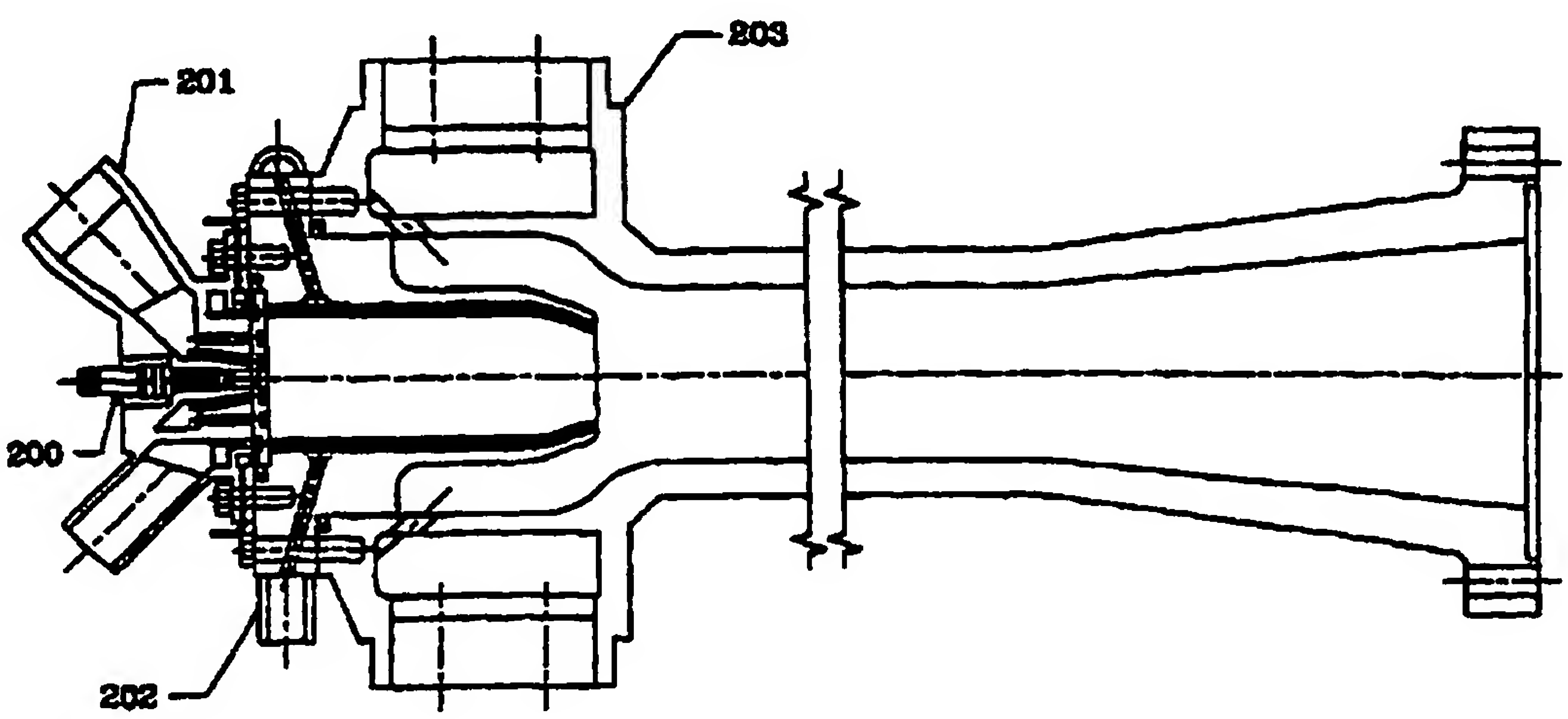

(57) Abstract

Pollution-free or low pollution, efficient, large scale electrical power generation systems, using thermal energy from combustion of hydrocarbon fuel are described herein. The pollutant-free hydrocarbon fuel is combusted in a gas generator with pure oxygen or substantially pure oxygen that is free of nitrogen. Water is also injected into the gas generator. The gas generator discharges high enthalpy steam and carbon dioxide which can then be utilized in a variety of applications, including driving turbines for power generation. The steam can be recycled into the gas generator or discharged for various uses. The carbon dioxide can be collected for industrial use or discharged.

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REDUCED POLLUTION POWER GENERATION SYSTEM AND GAS GENERATOR THEREFORE

Technical Field

This invention relates to systems for the efficient generation of environmentally clean energy by combustion of hydrocarbon fuel, focused on the commercial generation of electrical power. This invention also relates to low pollution gas generators for industrial applications where the working fluid used requires variable temperatures and pressures such as in food processing, oil well high energy gas injection, medical and greenhouse facility constant temperature control, and other applications.

Background Art

The current art in generating a major portion of commercial levels of electrical power, in the United States and world-wide, depends upon thermal generating plants burning hydrocarbon fuels (mainly coal and low grade fuel oils) with air, which contains 23.1% oxygen and 76.9% nitrogen by weight, to generate high enthalpy steam which, in turn, is used to drive turbo-electric generators.

The technology of designing, constructing and operating extremely high energy generators for jet engines, rocket engines, and gas turbine auxiliary power systems, has been significantly advanced in recent years. Generation and controlled use of such extremely high energy levels is a specialized practice and is readily adaptable to commercial industry.

The current state-of-the-art in power generation results in the production of atmospheric pollutants, mainly high levels of nitrogen oxides (NOx), sulfur oxides (SOx), carbon monoxide (CO) and particulate matter. Such emissions are at, and in a great many cases above, critical allowed threshold levels and must be reduced to preserve clean air. Current United States regulatory requirements prescribe the amounts of the above listed atmospheric emissions permitted in particular locations by a given power generating plant. Allowable emission thresholds are decreasing over time putting more and more pressure on industry to reduce emissions. Drastic economic penalties are being established, either in the form of fines (called purchased credits) related to the amounts by which emissions exceed allowable limits, or plants can be ordered to cease emitting operations.

In addition to the undesired effects of the build-up of atmospheric pollutants on the quality of the environment, current art extracts further societal prices in terms of the added costs of pollution control and monitoring equipment, and the purchasing of credits which are passed on to the consumers.

There have been many efforts to solve the emissions problem by exploiting non-combustible energy sources, such as windmills, fuel cells, solar cells, closed cycle solar reflector/boilers, use

of tidal motion and others. None of these sources can approach the required output levels in a cost-effective manner, with operating efficiency required for large-scale, sustained commercial applications currently supplied by the conventional thermal power generating plants. Nuclear plants can produce at the required levels of outputs, but they have encountered regulatory requirements leading to high costs, and there is a strong societal opposition to increasing use of nuclear power. Hence nuclear power use in the United States is severely restricted.

Disclosure of Invention

This invention is a unique, well developed technology for a high temperature, high pressure combustion device, designed to produce and control an efficient, high energy fluid stream, without generating unacceptable pollution, and which is usable in a variety of embodiments described in this application. The thermo-mechanical design and physical conformation are specific features the purposes of which are efficient operation, pollution avoidance, long life and minimum maintenance. These results are accomplished through unique integration of a number of advanced combustion technologies using selected reactants in a water cooled device generating a high purity steam and carbon dioxide working gas.

Elements of prior specialized technologies are adapted and combined in the design of a thermal power generating plant which can operate cleanly using any of several relatively inexpensive and widely available reactants including liquid oxygen, propane, methane, natural gas, or light alcohols such as ethanol and methanol. These reactants are or can be placed in mass commercial production and distribution, being already in extensive use in other fields such as home heating, cooking, industrial heating, metal cutting and welding, aerospace propulsion applications and others. Further, these reactants can be burned at high temperatures, in high pressure combustors which, while not currently widely used in the power industry, are a practiced art in the aerospace industries, but without emphasis on environmentally clean operation in those applications.

In this invention, the combustor is a high energy, continuous flow device. The liquid reactants (including a hydrocarbon fuel, oxygen and water diluent) are injected into a combustion chamber, via an efficient, high performance, specialized injection device, under high pressure, generating high temperature gas.

In combusting any of the fuels with liquid oxygen under controlled conditions (i.e., combustor pressure, temperature and fuel/ oxidizer mixture ratio), the products of combustion are high pressure, high temperature steam and gaseous carbon dioxide, with virtually no NOx, SOx, CO or particulates generated, depending upon the purity of the fuels and oxidizers used, and the controls of the combustion process. The carbon dioxide product can be recovered during the steam condensing process for commercial use. Current costs of the fuel elements generated in bulk by existing, large scale production facilities, are relatively cost competitive with coal and oil. The energy release in an appropriately scaled reactor produces power at a cost that is competitive

with current thermal plants, yet this invention will not yield the massive amounts of polluting gases, thus avoiding the additional penalty costs of pollution control equipment and purchased credits for excess emissions.

A specially configured version of this invention takes the form of a source of a high quality fluid, which can either improve a number of existing commercial applications (e.g. food processing, materials sterilization, oil well injection, etc.), or enable new applications such as intermediately scaled mobile plants for temporary, on-site power support, or non-polluting, steam powered drive systems for large locomotion systems such as trains or ships.

Brief Description of Drawings

Figure 1 is a schematic showing an embodiment of the invention, its elements and connectivity that constitute an efficient, pollution-free power generation system. Liquid reactants are shown being introduced to the system from sources that may be either on-site or adjacent production facilities, or from storage facilities. This embodiment features system enhancing elements which maximize energy utilization and minimize component size through turbine drive gas regeneration and inter-turbine drive gas reheating.

Figure 2 is a schematic showing an embodiment of the system from which the inter-turbine reheaters were removed, which simplifies the system of Figure 1, reduces cost, and slightly increases performance, but at the expense of increased component sizes and weights.

Figure 3 is a schematic showing an embodiment of the system from which both the reheaters and regenerators were removed, which simplifies the system of Figure 2, further reduces cost and decreases system performance, but at the expense of further increased component sizes and weights.

Figure 4 is a schematic showing an adaptation of embodiment 3, from which the recirculating water circuit and customer supplied heat rejection system were eliminated, with water supplied from a source (e.g., lake, river, or purified sea water), thus eliminating the complexity and cost of the closed loop water recovery and heat rejection subsystems.

Figure 5 is an illustration of an embodiment of the basic concept which uses those elements of the system required to generate the drive gas only. The generation of the high pressure, high temperature, high purity steam and carbon dioxide mixture that this system is capable of delivering has multiple industrial applications (e.g's., oil well injection, material sterilization, or heating of large structures or building complexes, and others).

Figure 6 is an illustration of an embodiment that is a modification of Figure 5, wherein the gas generator output is used to power a turbogenerator set, with components sized to mount on a mobile platform for applications such as remote site construction or exploration, auxiliary or peaking power supply, service power, or large locomotive drive applications, such as for trains or ships.

Figure 7 is a cut-away diagram showing the elements of the main reactor (or gas generator). This illustration shows the functional elements of the device, including the reactants' inlets and manifolds, the injector, the transpiration cooled combustion chamber, and the internal mixing chamber and outlet.

Figure 8 is a cut-away of a typical inter-turbine reheater. The device is a specialized version of the main reactor. The size of an individual reheater is dependent on the physical state of the out-flow received from the preceding turbine unit.

Best Modes for Carrying Out the Invention

Figure 1 illustrates a non-polluting, efficient electrical energy generating power plant 1000, comprising a reactant induction subsystem 100, a gas generation subsystem 200, a reheated turbine drive subsystem 300, an electrical energy generation subsystem 400, an exhaust management subsystem 500, and a regenerated water management subsystem 600.

The reactant service subsystem 100 feeds and controls the flow of the fuel and oxidizer reactants that power this system. This includes a liquid oxygen (LOX) feed line 1, feeding the LOX pump 2, which is powered by drive unit 6. The LOX pump 2 delivers high pressure LOX to the system gas generator subsystem 200, via the discharge line 3. High pressure gaseous or liquid fuel is delivered to the gas generator subsystem 200 through feed line 4.

The drive gas generator subsystem 200 includes a gas generator 7, which efficiently combusts the injected reactants under controlled conditions, producing a high pressure, high temperature gaseous mixture of steam and carbon dioxide which is delivered as a turbine drive gas. The drive gas is delivered to the high pressure turbine drive 13, in subsystem 300, via discharge line 10. Thermal control of the combustion process can be accomplished by controlling cooling water flow rate to the gas mixing chamber and to the chamber structure via water feed lines 64 and 66, supplied by water service feed line 65, from the water management subsystem 600.

The turbine drive subsystem 300, converts the gas generator subsystem 200 output energy into mechanical energy to drive the electrical generator subsystem 400. The turbine subsystem 300, consists of three power turbines, pressure staged for optimum efficiency, and two inter-turbine reheater units to maximize the energy in the drive gas.

The turbine drive subsystem 300 consists of high pressure power turbine 13, high pressure power turbine exhaust line 11, and high pressure power tap-off line 45. This assembly is followed by an inter-turbine reheater in which the exhaust temperature is brought back to that at the gas generator outlet by combusting the proper amount of the reactants in the reheater chamber and mixing the output with the main flow stream, thus adding energy and maintaining constant inlet temperature going into the next turbine. This takes place in the first inter-turbine reheater 62, which consists of the reheater 62, and reheater LOX feed line 56, reheater fuel feed line 57, reheater water feed line 68, high pressure turbine steam exhaust from line 11, and reheater

discharge line 59. This section is followed by a medium pressure range power turbine 14, medium pressure power turbine discharge line 12, medium power turbine tap-off line 15, followed by the second reheater unit consisting of inter-turbine reheater 63, reheater LOX feed line 58, reheater fuel feed line 60, reheater water feed line 69, medium pressure turbine steam exhaust from line 12, and reheater discharge line 61. The turbine power section is terminated by a low pressure power turbine 17, and discharge line 25, which sends the gas flow to an exhaust recovery condenser 41, in the exhaust recovery subsystem 500.

The energy generation subsystem 400 is the electrical energy conversion facility 18, consisting of electrical generator(s), and power conditioning, which develop the end product of this plant, electrical energy.

The exhaust management subsystem 500 is a gas handling subsystem with two purposes: (i) to make the most efficient use of the exhaust products, and (ii) to verify that pollution controls are effective. This subsystem consists of a carbon dioxide recovery branch and a water recovery branch, both serviced by the heat rejection facility 30.

The carbon dioxide recovery assembly receives near ambient temperature, gaseous carbon dioxide (CO2) from the condenser 41, via discharge line 19, and from the water management subsystem 600, via discharge line 47, into compressor 20, which is powered by drive unit 21. After one stage of compression, the gas is delivered to a water cooler 26, via discharge line 23, and, after cooling by passage through the heat exchanger section of the cooler vessel 26, the fluid is returned to compressor 20, via return line 24, and further compressed before discharge to facility return line 5, for recovery processing. Cooling water is supplied to cooler 26, from the heat rejection facility 30, by cooling water pump 34, powered by drive unit 36. Cooling water is drawn through inlet line 33, and delivered through pump discharge line 31, and cooler inlet line 28. After passing through the heat exchanger element in cooler 26, the cooling water is returned to the heat rejection facility 30, via discharge line 29. Carbon dioxide is also recovered from preheater 93 via discharge line 94.

The water recovery branch consists of the condenser vessel 41, cooling water inlet line 27, which sends cooling water through the condenser 41 heat exchanger section to cool down and condense the exhausted steam back to water. The cooling water is then returned to the heat rejection facility 30, via cooling water outlet line 22, and the condensed water is returned to the water management subsystem 600, via discharge line 37.

The water management subsystem 600 maintains the proper water balance in the operating system 1000. It does this by maintaining the proper cooling water injected at the gas generator inlet. The major product of combustion, using the reactants intended for this system, is water, therefore following start-up there is more than enough water available to operate the system. However, to insure adequate water availability during start-up, shut-down, and other transient operations, the heat rejection facility will serve as a reservoir as well as a receiver for any excess water generated. The main elements in the embodiment of the water management subsystem 600 are pressure staged pumps 16a, 16b, and 16c, powered commonly by drive unit 9, condensate

pump 38, powered by drive unit 39, and two (2) performance enhancing regenerator units 46 and 93.

The water recovered in the exhaust management subsystem 500 is returned to the water supply from condenser 41, discharge line 37, to condensate water pump 38, which is powered by drive unit 39. Condensate water pump 38 delivers the water to the feed water pumping system via discharge line 40. Excess water is diverted to the heat rejection facility 30, via return line 35, or any required start-up or make-up water is drawn from the heat rejection facility 30, via inlet line 95 and delivered to the inlet of pump 16a. The main water flow is delivered to the feed water pumps 16a, 16b, and 16c by the condensate pump 38, via feed line 43, which is joined by a recirculated flow from the medium pressure turbine tap-off line 15. This tap-off flow serves as the heat source in the heat exchange element of a regenerator device, regenerator 46, to conserve heat energy. The tap-off flow is collected in a sump in regenerator 46, and discharges to the low pressure feed water pump 16a, via discharge line 48, of regenerator 46 and pump 16a inlet line 43. An initial stage of feed water pressurization is accomplished in low pressure feed water pump 16a. The outflow of pump 16a is carried to regenerator 46, via discharge line 49, picks up heat energy in the heat exchanger element in regenerator 46, and then is passed to the medium pressure feed water pump 16b, via heat exchanger outlet line 50 and through inlet line 51. The water flow is joined by a recirculated flow that originates from the high pressure power turbine tap-off line 45. This tap-off flow serves as the heat source in the heat exchange element of the regenerator 93, to further conserve heat energy. The tap-off flow is collected in a sump in regenerator 93, and discharges to the medium pressure feed water pump 16b, via sump discharge line 92, of regenerator 93, and through medium pressure pump inlet line 51. The feed water flow stream is passed to the high pressure pump 16c, via medium pressure feed water pump 16b's discharge line 90. The high pressure pump 16c raises the main stream water pressure to the design level then discharges it via discharge line 91, to the heat exchanger section of regenerator 93, where it picks up more heat energy before finally being passed to the gas generator subsystem 200, and the reheaters 62 and 63, in the power turbine subsystem 300, via discharge line 8, and reheater cooling water line 65. The feed water pumps 16a, 16b and 16c are powered by the common drive unit 9.

Figure 2 illustrates a non-polluting electrical energy generating plant 2000, comprising a reactant induction subsystem 100, a gas generation subsystem 200, a turbine drive subsystem 300, an electrical energy generation subsystem 400, an exhaust management subsystem 500, and a regenerated water management subsystem 600.

The reactant service subsystem 100 feeds and controls the flow of the fuel and oxidizer reactants that power this system. This includes a liquid oxygen (LOX) feed line 1, feeding the LOX pump 2, which is powered by drive unit 6. The LOX pump 2 delivers high pressure LOX to the system gas generator subsystem 200, via the discharge line 3. High pressure gaseous or liquid fuel is delivered to the gas generator subsystem 200 through feed line 4.

The drive gas generator subsystem 200 includes a gas generator 7, which efficiently combusts the injected reactants under controlled conditions, producing a high pressure, high temperature gaseous mixture of steam and carbon dioxide which is delivered as a turbine drive gas. The drive gas is delivered to the turbine drive subsystem 300, via discharge line 10. Thermal control of the combustion process can be accomplished by controlling cooling water flow rate to the gas mixing chamber and to the chamber structure via water feed lines 64, supplied by water service feed line 65, which also feeds cooling water to the gas generator subsystem 200, from the water management subsystem 600.

The unreheated turbine drive subsystem 300, converts the gas generator subsystem 200 output energy into mechanical energy to drive the electrical generator subsystem 400. The turbine subsystem consists of three power turbines, pressure staged for optimum efficiency.

The turbine drive subsystem 300 consists of high pressure power turbine 13, high pressure power turbine exhaust line 11, and high pressure power tap-off line 45. This assembly is followed by a medium pressure power turbine 14, medium pressure power turbine discharge line 12, and medium power turbine tap-off line 15. The turbine power subsystem 300 is terminated by a low pressure power turbine 17, and discharge line 25, which sends the gas flow to an exhaust recovery condenser 41, in the exhaust recovery subsystem 500.

The energy generation subsystem 400 is the electrical energy conversion facility 18, consisting of electrical generator(s), and power conditioning, which develop the end product of this plant, electrical energy.

The exhaust management subsystem 500 is a gas handling subsystem with two purposes: (i) to make the most efficient use of the exhaust products, and (ii) to verify that pollution controls are effective. This subsystem consists of a carbon dioxide recovery branch and a water recovery branch, both serviced by heat rejection facility 30.

The carbon dioxide recovery assembly receives near ambient temperature, gaseous carbon dioxide ($CO2$) from the condenser 41, via discharge line 19, and from the water management subsystem 600, via regenerator 46 $CO2$ gas discharge lines 47, into compressor 20, which is powered by drive unit 21. After a stage of compression, the gas is delivered to a water cooled heat exchanger in cooler unit 26, via discharge line 23. After cooling by passage through the cooler vessel 26, the fluid is returned to the compressor 20, via return line 24, and further compressed before discharge to facility return line 5, for recovery processing. Cooling water is supplied to the cooler 26, from the heat rejection facility 30, by cooling water pump 34, powered by drive unit 36. Cooling water is drawn through inlet line 33, and delivered through pump discharge line 31, and cooler inlet line 28. After passing through the heat exchanger element in cooler 26, the cooling water is returned to the heat rejection facility 30, via discharge line 29. Carbon dioxide is also recovered from pre-heater 93 via discharge line 94.

The water recovery branch consists of the condenser vessel 41, cooling water inlet line 27, which sends cooling water through the condenser 41 heat exchanger section to cool down and condense the exhausted steam back to water. The cooling water is then returned to the heat

rejection facility 30, via cooling water outlet line 22, and the condensed water is returned to the water management subsystem 600, via discharge line 37.

The water management subsystem 600 maintains the proper water balance in the operating system 2000. It does this by maintaining the proper cooling water injected at the gas generator inlet. The major product of combustion, using the reactants intended for this system, is water, therefore following start-up there is more than enough water available to operate the system. However, to insure adequate water availability during start-up, shut-down, and other transient operations, the heat rejection facility will serve as a reservoir as well as a receiver for any excess water generated. The main elements in the embodiment of the water management subsystem 600 are pressure staged pumps 16a, 16b, and 16c, driven commonly by drive unit 9, two (2) performance enhancing regenerator units 46 and 93, and a condensate pump 38, powered by drive unit 39.

The water recovered in the exhaust management subsystem 500 is returned to the water supply from condenser 41, via discharge line 37, to condensate water pump 38, which is powered by drive unit 39. Condensate water pump 38 delivers the water to the feed water pumping system via discharge line 40. Excess water is diverted to the heat rejection facility 30, via return line 35, or any required start-up or make-up water is drawn from the heat rejection facility 30, via inlet line 95 and delivered to the inlet of water pump 16a. The main water flow is delivered to the feed water pumps 16a, 16b and 16c by the condensate pump 38, via feed line 43, which is joined by a recirculated flow from the medium pressure turbine tap-off line 15. This tap-off flow serves as the heat source in the heat exchange element of regenerator 46, to conserve heat energy. The tap-off flow is collected in a sump in regenerator 46, and discharges to the low pressure feed water pump 16a, via discharge line 48, of regenerator 46 and pump 16a inlet line 43. An initial stage of feed water pressurization is accomplished in low pressure feed water pump 16a. The outflow of pump 16a is carried to regenerator 46, via discharge line 49, picks up heat energy in the heat exchanger element in regenerator 46, and then is passed to the medium pressure feed water pump 16b, via regenerator 46 discharge line 50, through inlet line 51. The water flow is joined by a recirculated flow that originates from the high pressure power turbine tap-off line 45. This tap-off flow serves as the heat source in the heat exchange element of the regenerator 93, to further conserve heat energy. The tap-off flow is collected in a sump in regenerator 93, and discharges to the medium pressure feed water pump 16b, via sump discharge line 92, of regenerator 93, and through medium pressure pump inlet line 51. The feed water flow stream is passed to the high pressure pump 16c, via medium pressure feed water pump 16b's discharge line 90. The high pressure pump 16c raises the main stream water pressure to the design level then discharges it via discharge line 91, to the heat exchanger section of regenerator 93, where it picks up more heat energy before finally being passed to the gas generator subsystem 200, via discharge line 8, and cooling water lines 64 and 65. The feed water pumps 16a, 16b and 16c are powered by the common drive unit 9.

Figure 3 illustrates a non-polluting, efficient electrical energy generating power plant 3000, comprising a reactant induction subsystem 100, a gas generation subsystem 200, a turbine drive subsystem 300, an electrical energy generation subsystem 400, an exhaust management subsystem 500, and an unregenerated water management subsystem 600.

The reactant service subsystem 100 feeds and controls the flow of the fuel and oxidizer reactants that power this system. This includes a liquid oxygen (LOX) feed line 1, feeding the LOX pump 2, which is powered by drive unit 6. The LOX pump 2 delivers high pressure LOX to the system gas generator subsystem 200, via the discharge line 3. High pressure gaseous or liquid fuel is delivered to the gas generator subsystem 200 through feed line 4.

The drive gas generator subsystem 200 includes a gas generator 7, which efficiently combusts the injected reactants under controlled conditions, producing a high pressure, high temperature gaseous mixture of steam and carbon dioxide which is delivered as a turbine drive gas. The drive gas is delivered to the turbine drive subsystem 300, via discharge line 10. Thermal control of the combustion process can be accomplished by controlling cooling water flow rate to the gas mixing chamber and to the chamber structure via water feed lines 64 and 65, from the water management subsystem 600.

The turbine drive subsystem 300, converts the gas generator subsystem 200 output energy into mechanical energy to drive the electrical generator subsystem 400.

The turbine subsystem consists of three power turbines, pressure staged for optimum efficiency. The turbine drive subsystem 300 consists of high pressure power turbine 13, and high pressure power turbine exhaust line 11. This assembly is followed by a medium pressure power turbine 14, and medium pressure power turbine discharge line 12. The turbine power subsystem 300 is terminated by a low pressure power turbine 17, and discharge line 25, which sends the gas flow to an exhaust recovery condenser 41, in the exhaust recovery subsystem 500.

The energy generation subsystem 400 is the electrical energy conversion facility 18, consisting of electrical generator(s), and power conditioning, which develop the end product of this plant, electrical energy.

The exhaust management subsystem 500 is a gas handling subsystem with two purposes: (i) to make the most efficient use of the exhaust products, and (ii) to verify that pollution controls are effective. This subsystem consists of a carbon dioxide recovery branch and a water recovery branch, both serviced by a heat rejection facility 30.

The carbon dioxide recovery assembly receives near ambient temperature, gaseous carbon dioxide (CO2) from condenser 41, via discharge line 19, into compressor 20, which is powered by drive unit 21. After one stage of compression, the gas is delivered to a water cooled heat exchanger in cooler unit 26, via discharge line 23. After cooling by passage through the cooler vessel 26, the fluid is returned to the compressor 20, via return line 24, and further compressed before discharge to facility return line 5, for recovery processing. Cooling water is supplied to the cooler 26, from the heat rejection facility 30, by cooling water pump 34, powered by drive unit 36. Cooling water is drawn through inlet line 33, and delivered through pump discharge line

31, and cooler inlet line 28. After passing through the heat exchanger element in cooler 26, the cooling water is returned to the heat rejection facility 30, via discharge line 29.

The water recovery branch consists of the condenser vessel 41, cooling water inlet line 27, which sends cooling water through the condenser 41 heat exchanger section to cool down and condense the exhausted steam back to water. The cooling water is then returned to the heat rejection facility 30, via cooling water outlet line 22, and the condensed water is returned to the water management subsystem 600, via discharge line 37.

The water management subsystem 600 maintains the proper water balance in the operating system 3000. It does this by maintaining the proper cooling water injected at the gas generator inlet. The major product of combustion, using the reactants intended for this system, is water, therefore following start-up there is more than enough water available to operate the system. However, to insure adequate water availability during start-up, shut-down, and other transient operations, the heat rejection facility will serve as a reservoir as well as a receiver for any excess water generated. The main elements in the embodiment of the water management subsystem 600 are pressure staged pumps 16a, 16b, and 16c, powered commonly by drive unit 9, and a condensate pump 38, driven by drive unit 39.

The water recovered in the exhaust management subsystem 500 is returned to the system water supply from condenser 41, discharge line 37, to condensate water pump 38, which is powered by drive unit 39. Condensate water pump 38 delivers the water to the feed water pumping system via discharge line 40. Excess water is diverted to the heat rejection facility 30, via return line 35, or any required start-up or make-up water is drawn from the heat rejection facility 30, via inlet line 95 and delivered to the inlet of water pump 16a. The main water flow is delivered to feed water pumps 16a, 16b and 16c. The condensate pump 38, sends the recovered water to the low pressure feed water pump 16a, via feed line 43. Initial feed water pressurization is accomplished in low pressure feed water pump 16a. The outflow of pump 16a is carried to medium pressure feed water pump 16b by feed water line 49. The medium pressure feed water pump 16b raises the feed water pressure further and passes the feed water flow stream to the high pressure pump 16c, via feed water line 90. The high pressure pump 16c raises the main stream water pressure to the design level before finally being passed to the gas generator subsystem 200 via discharge line 8 and inlet water lines 64 and 65.

Figure 4 illustrates a minimum polluting, efficient electrical energy generating power plant 4000, comprising a reactant induction subsystem 100, a gas generation subsystem 200, a turbine drive subsystem 300, an electrical energy generation subsystem 400, and a limited water management subsystem 600. The limited exhaust gas management subsystem 500 is eliminated in this embodiment. This embodiment has a reduced complexity, hence reduced costs, for both acquisition and maintenance.

The reactant service subsystem 100 feeds and controls the flow of the fuel and oxidizer reactants that power this system. This includes a liquid oxygen (LOX) feed line 1, feeding the LOX pump 2, which is powered by drive unit 6. The LOX pump 2 delivers high pressure LOX

to the system gas generator subsystem 200, via the discharge line 3. High pressure gaseous or liquid fuel is delivered to the gas generator subsystem 200 through feed line 4.

The drive gas generator subsystem 200 includes a gas generator 7, which efficiently combusts the injected reactants under controlled conditions, producing a high pressure, high temperature gaseous mixture of steam and carbon dioxide which is delivered as a turbine drive gas. The drive gas is delivered to the turbine drive subsystem 300, via discharge line 10. Thermal control of the combustion process can be accomplished by controlling cooling water flow rate to the gas mixing chamber and to the chamber structure via water feed lines 64 and 65. This embodiment is suited for sites where water availability makes the complexity and cost of a water recovery system unnecessary.

The turbine drive subsystem 300, converts the gas generator subsystem 200 output energy into mechanical energy to drive the electrical generator subsystem 400. The turbine subsystem consists of three power turbines, pressure staged for optimum efficiency.

The turbine drive subsystem 300 consists of high pressure power turbine 13, and high pressure power turbine exhaust line 11. This assembly is followed by a medium pressure power turbine 14, and medium pressure power turbine discharge line 12. The turbine power subsystem 300 is terminated by a low pressure power turbine 17, and discharge line 25, which discharges the exhaust to the atmosphere.

The energy generation subsystem 400 is the electrical energy conversion facility 18, consisting of electrical generator(s), and power conditioning, which develop the end product of this plant, electrical energy.

In this embodiment the exhaust management subsystem 500 is deleted and the low pressure turbine exhaust gases are vented to the atmosphere.

For this embodiment the water management subsystem 600 draws cooling water from a nearby water source. The main elements in this embodiment of water management subsytem 600 are pressure staged pumps 16a, 16b, and 16c, powered commonly by drive unit 9. The water flow is drawn by the feed water pumps 16a, 16b, and 16c, through intake line 43. The initial stage of feed water pressurization is accomplished in low pressure feed pump 16a. The outflow of pump 16a is carried via discharge line 49, to the medium pressure feed water pump 16b. From medium pressure feed pump 16b, the feed water flow stream is passed to the high pressure pump 16c, via medium pressure feed water pump 16b's discharge line 90. The high pressure pump 16c raises the main stream water pressure to its design level and delivers the water to the gas generator subsystem 200 via discharge line 8 and cooling water lines 64 and 65.

Figure 5 illustrates a non-polluting, high energy industrial fluid generation plant 5000, comprising a reactant service subsytem 700, and a gas generation subsystem 200.
The reactant service subsystem 700 feeds and controls the flow of fuel and oxidizer reactants that power this system. This includes a liquid oxygen inlet line 1, feeding a high pressure LOX pump 2, driven by drive unit 6. The LOX pump 2, delivers high pressure LOX to the gas generator subsytem 200, via the pump discharge line 3. Inlet line 80 feeds liquid fuel to high

pressure pump 81, which is powered by drive unit 82. Pump 81 delivers high pressure fuel to the gas generator subsystem 200 via discharge line 4. Inlet line 43 delivers cooling feed water to the high pressure pump 16, which is powered by drive unit 9. The high pressure cooling water is delivered to the gas generator subsystem 200 via pump discharge line 8. This flow is split at line 8 outlet into cooling water for delivery to the gas generator 200's internal combustor chamber cooling via feed line 64, and to the internal gas-water mixing chamber section via inlet line 65.

The drive gas generator subsystem 200 includes a gas generator 7, which combusts the injected reactants under controlled conditions, producing a high pressure, high temperature gaseous mixture of steam and carbon dioxide, a high energy fluid suitable for a wide range of industrial applications, via discharge line 10. Thermal control of the combustion process is accomplished by controlling cooling water flow rate to an internal combustion chamber and to the gas-water mixing chamber via water feed lines 64 and 65.

Figure 6 illustrates a non-polluting, efficient, auxiliary and/or transportation power system 6000. This embodiment augments embodiment 5000, subsystems 700 and 200 with an energy conversion subsystem 900, to produce a power system that can be scaled in size to a wide spectrum of industrial applications (e.g's., standby emergency power, peaking power, portable remote site power, nonpolluting steam train power, ocean-going vessels, and many other similar applications).

The reactant service subsytem 700 feeds and controls the flow of fuel and oxidizer reactants that power this system and the gas generator subsystem 200 cooling water. This includes a liquid oxygen inlet line 1, feeding a high pressure LOX pump 2, which is driven by drive unit 6. The LOX pump 2 delivers high pressure LOX to the gas generator subsytem 200, via the pump discharge line 3. Inlet line 80 feeds liquid fuel to high pressure pump 81, which is powered by drive unit 82. Pump 81 delivers high pressure fuel to the gas generator subsystem 200 via discharge line 4. Inlet line 43 delivers cooling feed water to the high pressure pump 16, which is powered by drive unit 9. The high pressure cooling water is delivered to the gas generator subsystem 200 via pump discharge line 8.

The drive gas generator subsystem 200 includes a gas generator 7, which combusts the injected reactants under controlled conditions, producing a high pressure, high temperature gaseous mixture of steam and carbon dioxide, a high energy drive fluid delivered to the drive turbine 17, of the energy generation subsystem 900, via discharge line 10. Thermal control is accomplished by controlling cooling water flow rate picked up from discharge line 8 of the reactant service subsystem 700. This flow stream is split and directed to an internal combustion chamber via inlet line 64, and to the main mixing chamber section via water inlet line 65.

The energy generation subsystem 900 is the electrical energy conversion facility power turbine 17, and the electric motor/ generator unit 18, which can be harnessed to any number of industrial applications.

Figure 7 is a cut-away view of a unique, advanced technology combustor device which is the gas generator used to develop the high energy gas used in all the embodiments contained in

this application. Its configuration and operation are designed to develop and control the high energy, non-polluting fluid in the most efficient, cost-effective manner. The thermo-mechanical design and physical conformation are specific features the purposes of which are efficient operation, pollution avoidance, long life and minimum maintenance.

The device is composed of a start-up igniter 200, a fluid induction head 201, containing oxygen and gaseous or liquid fuel inlets and integral distribution channels, an injector face water cooling inlet and distribution circuitry, a microported reactant injector body, and a water cooled combustor. The fluid induction head interfaces with an adapter block 202 which contains an inlet and distribution passages to feed cooling water to the wall of the combustor element of the fluid induction head. The adapter block 202 is also the interface to the device mixing chamber 203. The mixing chamber has inlets for the induction of the major portion of the water flow which mixes with the hot gas in the chamber to attain the design drive gas temperature. In addition, the manner in which this flow stream is introduced cools the walls of the mixing chamber, maintaining wall temperature at the design level.

Figure 8 is a cut-away view of a unique, advanced technology drive gas reheater which can be used to boost the temperature of a drive gas stream after it has passed through an energy extracting device like a power turbine. While this approach to energy management in a power system has a small penalty in overall system efficiency, it allows a reduction in the size and weight of certain components. The thermo-mechanical design and physical conformation are specific features, the purposes of which are efficient operation, long life and minimal maintenance.

The device is composed of the same start-up igniter 200 used in the gas generator, Figure 7, a fluid management head 201 containing oxygen and fuel inlets and integral distribution channels, an injector face water cooling inlet and distribution circuitry, a microported reactant injector body, and a water cooled combustor. This item is the same as item 202 in the gas generator in Figure 7. The fluid induction head interfaces with an adapter block 204 which contains an inlet and distribution passages to feed cooling water to the wall of the combustor element of the fluid induction head 201. The adapter block 204 is similarly configured to item 201 in the gas generator device in Figure 7, except that the outer flange diameter is sized to interface with the gas induction and mixing chamber 205. The mixing chamber has inlets for the induction of the gas flow from the preceding device (e.g., preceding turbine exhaust) and to mix the inducted gas with the hot gas generated in the preheater combustor in item 204. This mixing is done to raise the inducted gas temperature back to the same level it had at the entrance of the preceding device. This element is similar to that in Figure 7, except that its fore and aft diameters are matched to the preceding and following devices in the total gas flow path, and the inlets induct gas rather than water and are sized accordingly.

Industrial Applicability

This invention exhibits industrial applicability in that it provides for the efficient generation of energy in an environmentally clean manner, such as for the commercial generation of electrical power. This invention utilizes combustion of a hydrocarbon fuel, and yet still exhibits potential in meeting low pollution emission standards. This invention has a number of additional industrial applications where the working fluid used requires variable temperatures and pressures such as in food processing, oil well high energy gas injection, medical and greenhouse facility constant temperature control, and other applications.

Each embodiment of the invention is composed of subsystems and/or individual elements which tailor each system to an operating environment that requires different implementation modes or applications. For instance, two embodiments are configured to adapt smaller scale power plants to applications such as platform mounted portable power applications, large vehicle propulsion, and other applications. Also, the invention can be configured to produce high quality fluid at controlled pressures and temperatures as required by a wide range of industrial applications.

CLAIMS

What is claimed is:

Claim 1 - A regenerative turbine power generating system with reheating between turbines, using as the working fluid the products of complete combustion of oxygen and a hydrocarbon or simple alcohol (e.g., methanol or ethanol) fuel, combined with a water quench, said regenerative turbine power generating system comprising:

a pump means having an inlet adapted to receive low pressure liquid oxygen from a supply means and having a discharge, said pump including means to raise the pressure of said liquid oxygen to a value greater than at its inlet;

an input means for receiving a high pressure hydrocarbon or simple alcohol (e.g. methanol or ethanol) fuel from a supply means and having a discharge;

a high pressure water pump means having an inlet adapted to receive lower pressure water from a supply means and having a discharge, said pump including means to raise the pressure of said water to values greater than at its inlet;

a gas generator means, including inlet means for receiving said high pressure liquid oxygen, said high pressure hydrocarbon or simple alcohol type fuel and said high pressure water, means to completely combust said high pressure liquid oxygen with said high pressure fuel to generate a high temperature gas of steam and carbon dioxide, means to quench said high temperature gas with said high pressure water to generate a lower temperature mixture of steam and carbon dioxide gas, and having an output;

a first turbine means including means to receive said gas generator output gas, adapted to deliver output power and having an exhaust;

a first reheater means including a means for receiving said first turbine exhaust, means for receiving a portion of said high pressure liquid oxygen, means for receiving a portion of said high pressure fuel, means for receiving a portion of said high pressure water, water cooled combustor means to completely combust said high pressure liquid oxygen with said high pressure fuel to generate a high temperature gas and having an exhaust, means for mixing said first turbine exhaust gas with said combustor exhaust to produce a completely mixed reheater gas having a temperature near that of the said gas generator exhaust and having a discharge;

a second turbine including means to receive said output gas from said first reheater discharge, adapted to deliver output power and having an exhaust;

a second reheater means including a means for receiving said second turbine exhaust, means for receiving a portion of said high pressure liquid oxygen, means for receiving a portion of said high pressure fuel, means for receiving a portion of said high pressure water, water cooled combustor means to completely combust said high pressure liquid oxygen with said high pressure fuel to generate a high temperature gas flow and having an exhaust;

means for mixing said second turbine exhaust with said high temperature combustor exhaust gas to produce a completely mixed reheater gas having a temperature near that of the said gas generator exhaust and having a discharge;

a third turbine including means to receive said output gas from said second reheater discharge, adapted to deliver output power and having an exhaust;

a condenser means, including means to receive said output gas from said third turbine exhaust, means to condense said third turbine exhaust steam and means to cool said third turbine exhaust carbon dioxide gas and adapted to have a water discharge and a gaseous carbon dioxide discharge;

a compressor means having an inlet adapted to receive said gaseous carbon dioxide from said condenser carbon dioxide discharge, means to raise said gaseous carbon dioxide pressure to a value greater than at its inlet pressure, and having a discharge;

a low pressure water pump means having an inlet adapted to receive water from said condenser water discharge, means to raise the pressure of said water to a value greater than at its inlet, and having a discharge;

a first regenerator means adapted with means to receive a portion of said first turbine exhaust and means to receive water from a high pressure stage of said high pressure water pump, means for exchanging heat from said portion of first turbine exhaust with said high pressure water,and adapted with separate outlets for discharging cooled carbon dioxide gas, low pressure condensed water and high pressure heated water;

a second regenerator means adapted with means to receive a portion of said second turbine exhaust and means to receive water from a low pressure stage of said high pressure water pump, means for exchanging heat from said portion of second turbine exhaust with said low pressure water, and adapted with separate outlet means for discharging cooled carbon dioxide gas, low pressure condensed water and low pressure heated water.

Claim 2 - A steam generating system using as the working fluids the products of a complete combustion of oxygen and a hydrocarbon or simple alcohol fuel combined with a water quench, said steam generating system comprising:

a pump means having an inlet adapted to receive low pressure liquid oxygen from a supply means and having a discharge, said pump including means to raise the pressure of said liquid oxygen to a value greater than at its inlet;

an input means for receiving a high pressure hydrocarbon or simple alcohol fuel from a supply means and having a discharge;

a high pressure water pump means having an inlet adapted to receive low pressure water from a supply means and having a discharge, said pump including means to raise the pressure of said water to values greater than at its inlet;

a gas generator means, including inlet means for receiving said high pressure liquid oxygen, said high pressure hydrocarbon or simple alcohol fuel and said high pressure water, means to completely combust said high pressure liquid oxygen with said high pressure hydrocarbon or simple alcohol fuel to generate a high temperature gas of steam and carbon dioxide, means to quench said high temperature gas with said high pressure water to generate a lower temperature steam and carbon dioxide gas outflow, and having a discharge.

Claim 3 - A pollution-free power generating system comprising in combination:

a source of elevated pressure oxygen, substantially free of nitrogen;

a source of elevated pressure fuel including compounds containing carbon and hydrogen; said fuel substantially free of chemical elements that are precursors to combustion formed pollutants, such elements including nitrogen, sulfur, phosphorus and halogens;

a source of water;

a gas generator including at least one fuel inlet coupled to said source of elevated pressure fuel, at least one oxygen inlet coupled to said source of elevated pressure oxygen, a means to initiate combustion of said fuel within said generator, at least one water flow inlet coupled to said source of water and spaced from said fuel inlet and said oxygen inlet, a mixing chamber wherein products of combustion of the fuel and the oxygen can mix with the water from the water flow inlet , and a discharge for a mixture of gaseous products of combustion and gaseous phase water from said water flow inlet;

means to generate power from expansion of said gas exiting said discharge; and

means to separate and collect said products of combustion other than water;

whereby energy is extracted from said fuel without release of pollutants.

Claim 4 - The system of claim 3 wherein said gas generator includes an enclosure supporting said oxygen inlet and said fuel inlet adjacent each other and said water flow inlet oriented between said oxygen inlet and said fuel inlet on a first side and said discharge on a second side, said water flow inlet spaced from said oxygen inlet and said fuel inlet by a distance sufficient to allow a majority of said fuel to combust before mixing with said water entering said enclosure from said water flow inlet, and wherein said source of elevated pressure oxygen includes a source of elevated pressure liquid oxygen.

Claim 5- The system of claim 4 wherein water distribution circuitry is coupled to said source of water and oriented adjacent said fuel inlet and said oxygen inlet, whereby the combustion temperature of said fuel with said oxygen adjacent said fuel inlet and said oxygen inlet can be controlled.

Claim 6 - The system of claim 5 wherein said water distribution circuitry includes a water cooling inlet adjacent said oxygen inlet and said fuel inlet, directing water into said enclosure.

Claim 7 - The system of claim 6 wherein said oxygen inlet, said fuel inlet and said water distribution circuitry are located within an induction head forming a portion of said gas generator enclosure, said induction head exposed to a mixing chamber spaced from said induction head and forming a portion of said enclosure, said mixing chamber supporting said water flow inlet and said discharge.

Claim 8 - The system of claim 7 wherein said separation means includes a condenser, said condenser including means to condense water from said gas exiting said discharge, and means to collect carbon dioxide and all other gaseous products of combustion from said gas generator.

Claim 9 - The system of claim 8 wherein said power generating means is at least one turbine coupled to an electric generator, said turbine receiving gas including steam and carbon dioxide from said discharge of said gas generator and expanding said gas to a lower pressure and driving said electric generator.

Claim 10 - The system of claim 9 wherein said power generating means includes at least two turbines with a reheater interposed between at least one adjacent pair of said turbines.

Claim 11 - The system of claim 10 wherein said reheater includes at least one reheater fuel inlet coupled to said source of elevated pressure fuel, at least one reheater oxygen inlet coupled to said source of elevated pressure liquid oxygen, a means to initiate combustion of said fuel within said reheater, said reheater fuel inlet and said reheater oxygen inlet oriented adjacent each other within a reheater enclosure, at least one reheater gas flow inlet coupled to an outlet of a higher pressure one of said pair of turbines and spaced from said fuel inlet and said oxygen inlet within said reheater enclosure, and a reheater discharge for discharging from said enclosure a mixture of gaseous products of combustion and gaseous phase reheater gas flow from said outlet of said higher pressure one of said pair of turbines.

Claim 12 - The system of claim 11 wherein said source of water is coupled to said condenser such that said source of water is replenished with water from said condenser to form a closed cycle, and wherein a regenerator is provided between said source of water and said gas generator, said regenerator coupling water from said source of water through a heat exchange wall to a tap-off from an outlet of one of said turbines, such that heat from gas in said tap-off is transferred to the water from said source of water before the water enters said gas generator, whereby the efficiency of said system is enhanced.

Claim 13 - The system of claim 3 wherein said power generation means is a turbine coupled to an electric generator, said turbine having a turbine discharge coupled to a condenser for condensation of portions of said gas including water into a liquid state and separation of portions of said gas including carbon dioxide which remain in a gaseous state.

Claim 14 - The system of claim 13 wherein at least one feed water pump returns a portion of the water condensed by said condenser back to said gas generator, and wherein a portion of the gas generated by said gas generator and expanded through said turbine is tapped off to provide heat to the water between said feed water pump and said gas generator.

Claim 15 - A method for power generation from combustion of a fuel without production of any polluting emissions, including the steps of:

providing a source of elevated pressure oxygen, substantially free of nitrogen;

providing a source of elevated pressure fuel including compounds containing carbon and hydrogen; said fuel substantially free of chemical elements that are precursors to combustion formed pollutants, such elements including nitrogen, sulfur, phosphorus and halogens;

providing a source of water;

providing a gas generator having an enclosure including a means to initiate combustion therein, a mixing chamber and a discharge;

inputting oxygen from the source of oxygen into the enclosure;

inputting fuel from the source of fuel into the enclosure;

combusting the fuel within the enclosure to produce products of combustion;

entering water into the enclosure;

mixing the entered water with the products of combustion to produce a gas;

discharging the gas from the enclosure;

expanding the gas while extracting energy from the gas to produce power; and

separating non-water portions of the gas from the gas;

whereby power is produced from combustion of the fuel and oxygen without emission of any pollutants into the environment.

Claim 16 - A power generating system which combusts hydrocarbon fuel while emitting an amount of pollution which is reduced with respect to typical combustion based power generating systems, comprising in combination:

a source of hydrocarbon fuel;

a source of oxygen;

a source of water;

a gas generator including a fuel inlet coupled to said source of fuel, an oxygen inlet coupled to said source of oxygen, means to ignite said fuel, a water inlet coupled to said source of water and a discharge; and

means to extract power from high energy products of combustion within said gas generator, said power extraction means coupled to said discharge.

Claim 17 - The power generating system of claim 16 wherein said fuel is substantially free of pollutants and includes elements taken from the group including one or more of the elements hydrogen, carbon and oxygen, and

means to deliver said fuel and said oxygen into said gas generator at the stoichiometric ratio necessary for combustion of the fuel with the oxygen to produce substantially only water and carbon dioxide.

Claim 18 - The power generating system of claim 17 wherein said gas generator includes a means to provide thermal control of a combustion reaction occurring within said gas generator, said thermal control means including said water inlet delivering water from said source of water into said gas generator.

Claim 19 - The power generating system of claim 18 wherein said power extraction means includes a turbine coupled to said discharge such that products of combustion within said gas generator drive said turbine, said turbine coupled to a power generating device.

Claim 20 - The power generating system of claim 19 wherein said source of water includes water created from combustion within said gas generator and exiting an exhaust of said turbine, and wherein a portion of said water exiting said exhaust of said turbine is discharged out of said system and into the environment.

Claim 21 - A gas generator for a low or zero emissions power generating system, comprising in combination:

an enclosure including a combustor portion, a mixing chamber and a discharge;

at least one high pressure oxygen inlet into said combustor portion of said enclosure coupled to a source of oxygen;

at least one high pressure fuel inlet into said combustor portion of said enclosure coupled to a source of fuel;

at least one water distribution circuit oriented within walls of said combustor portion of said enclosure; and

at least one water flow inlet into said mixing chamber of said enclosure.

Claim 22 - The gas generator of claim 21 wherein said water distribution circuit includes inlets into said combustion portion of said enclosure, such that said water distribution circuit provides means to control the temperature of combustion of said fuel with said oxygen and the temperature of said walls of said combustion chamber.

Claim 23 - The gas generator of claim 22 wherein said water distribution circuit and said water flow inlet are coupled to a source of liquid water replenished from at least a portion of the gas generated within said gas generator and exiting said enclosure through said discharge.

Claim 24 - The gas generator of claim 23 wherein said mixing chamber is spaced from said fuel inlet and said oxygen inlet by a distance defining a length of said combustion portion which is sufficient to allow primarily only combustion products to enter said mixing chamber and contact water from said water flow inlet, and wherein an igniter is oriented within said combustion portion of said enclosure.

Claim 25 - The gas generator of claim 24 wherein said source of fuel is a source of hydrocarbon fuel including at least two elements taken from the group of elements including hydrogen, carbon and oxygen, and

wherein said oxygen inlet and said fuel inlet are configured to provide mixing of said fuel and said oxygen at a substantially stoichiometric ratio needed to produce combustion products including substantially only water and carbon dioxide.

Claim 26 - The gas generator of claim 21 wherein said source of fuel is a source of hydrocarbon fuel including methane.

Claim 27 - A gas generator for producing high pressure, high temperature steam directly from products of combustion, comprising in combination:

at least one oxygen inlet;

at least one fuel inlet, said fuel including hydrogen, carbon and optionally oxygen;

means to ignite the fuel such that combustion occurs and high pressure, high temperature steam is generated along with carbon dioxide.

Claim 28 - The gas generator of claim 27 wherein said oxygen inlet and said fuel inlet are configured to provide mixing of said fuel and said oxygen at a ratio needed to produce combustion products including substantially only water and carbon dioxide.

Claim 29 - The gas generator of claim 28 wherein said gas generator includes a means to control a temperature of said combustion products, and

wherein said gas generator includes a water inlet, at least a portion of said water inlet oriented proximate to said oxygen inlet and said fuel inlet, said water inlet providing water at a temperature below a temperature of said combustion products of said fuel and oxygen mixture, the water from said water inlet forming at least a portion of said means to control a temperature of said combustion products,

whereby a temperature of said combustion products remains optimal for complete combustion of said fuel and oxygen mixture.

Claim 30 - The gas generator of claim 29 wherein said oxygen inlet and said fuel inlet are oriented within an induction head of said gas generator, said induction head including pathways therein which form water distribution circuitry therein, said pathways coupled to said water inlet, such that at least a portion of the water from said water inlet passes through said pathways,

whereby said induction head is cooled by the water and a temperature of said fuel oxygen mixture is regulated.

Claim 31 - The gas generator of claim 30 wherein said gas generator includes a high pressure enclosure including said induction head, a combustion chamber and a discharge spaced from said induction head, said combustion chamber including a means to cool walls of said combustion chamber,

wherein at least a portion of the water from said water inlet is passed adjacent said walls of said combustion chamber, the water forming at least a portion of said wall cooling means.

Claim 32 - The gas generator of claim 31 wherein at least a portion of the water from said water inlet passes into said combustion chamber at a location spaced from said induction head, the water entering said combustion chamber having a sufficient flow rate and temperature to provide high pressure steam of desired temperature at said discharge, the discharged steam being a combination of the water from said water inlet and the water forming one component of said combustion products.

Claim 33 - The gas generator of claim 32 wherein said induction head includes regions therein for metering and mixing of fuel and oxygen at high pressure and at said ratio needed to produce combustion products including substantially only water and carbon dioxide.

Claim 34 - The gas generator of claim 33 wherein said induction head is microported between said metering and mixing regions and said combustion chamber, such that a plurality of ports for said fuel and oxygen mixture are provided into said combustion chamber.

Claim 35 - The gas generator of claim 28 wherein said fuel inlet and said oxygen inlet are oriented within an induction head, said induction head including regions therein for metering and mixing of fuel and oxygen at high pressure and at said ratio needed to produce combustion products including substantially only water and carbon dioxide.

Claim 36 - The gas generator of claim 35 wherein wherein said gas generator includes a means to control a temperature of said combustion products, and

wherein said gas generator includes a water inlet, at least a portion of said water inlet oriented proximate to said oxygen inlet and said fuel inlet, said water inlet providing water at a temperature below a temperature of said combustion products of said fuel and oxygen mixture, the water from said water inlet forming at least a portion of said means to control a temperature of said combustion products, whereby a temperature of said combustion products remains optimal for complete combustion of said fuel and oxygen mixture; and

wherein said induction head includes pathways therein which form water distribution circuitry therein, said pathways coupled to said water inlet, such that at least a portion of the water from said water inlet passes through said pathways, whereby said induction head is cooled by the water and a temperature of said fuel oxygen mixture is regulated.

Claim 37 - The gas generator of claim 36 wherein said gas generator includes a high pressure enclosure including said induction head, a combustion chamber and a discharge spaced from said induction head, said combustion chamber including a means to cool walls of said combustion chamber;

wherein at least a portion of the water from said water inlet is passed adjacent said walls of said combustion chamber, the water forming at least a portion of said wall cooling means; and

wherein at least a portion of the water from said water inlet passes into said combustion chamber at a location spaced from said induction head, the water entering said combustion chamber having a sufficient flow rate and temperature to provide high pressure steam of desired temperature at said discharge, the discharged steam being a combination of the water from said water inlet and the water forming one component of said combustion products.

Claim 38 - The gas generator of claim 37 wherein said water inlet receives at least a portion of the water delivered thereby from the high pressure steam exiting said discharge of said gas generator.

Claim 39 - A method for generating gas including high temperature, high pressure steam directly from products of combustion, including the steps of:

providing a source of elevated pressure oxygen;

providing a source of elevated pressure fuel, the fuel including hydrogen, carbon and optionally oxygen;

mixing the oxygen and the fuel at a stoichiometric ratio necessary to produce substantially only water and carbon dioxide upon combustion of the fuel with the oxygen;

porting the mixture of oxygen and fuel into a combustion chamber where an igniter is provided;

igniting the mixture of fuel and oxygen within the combustion chamber with the igniter; and

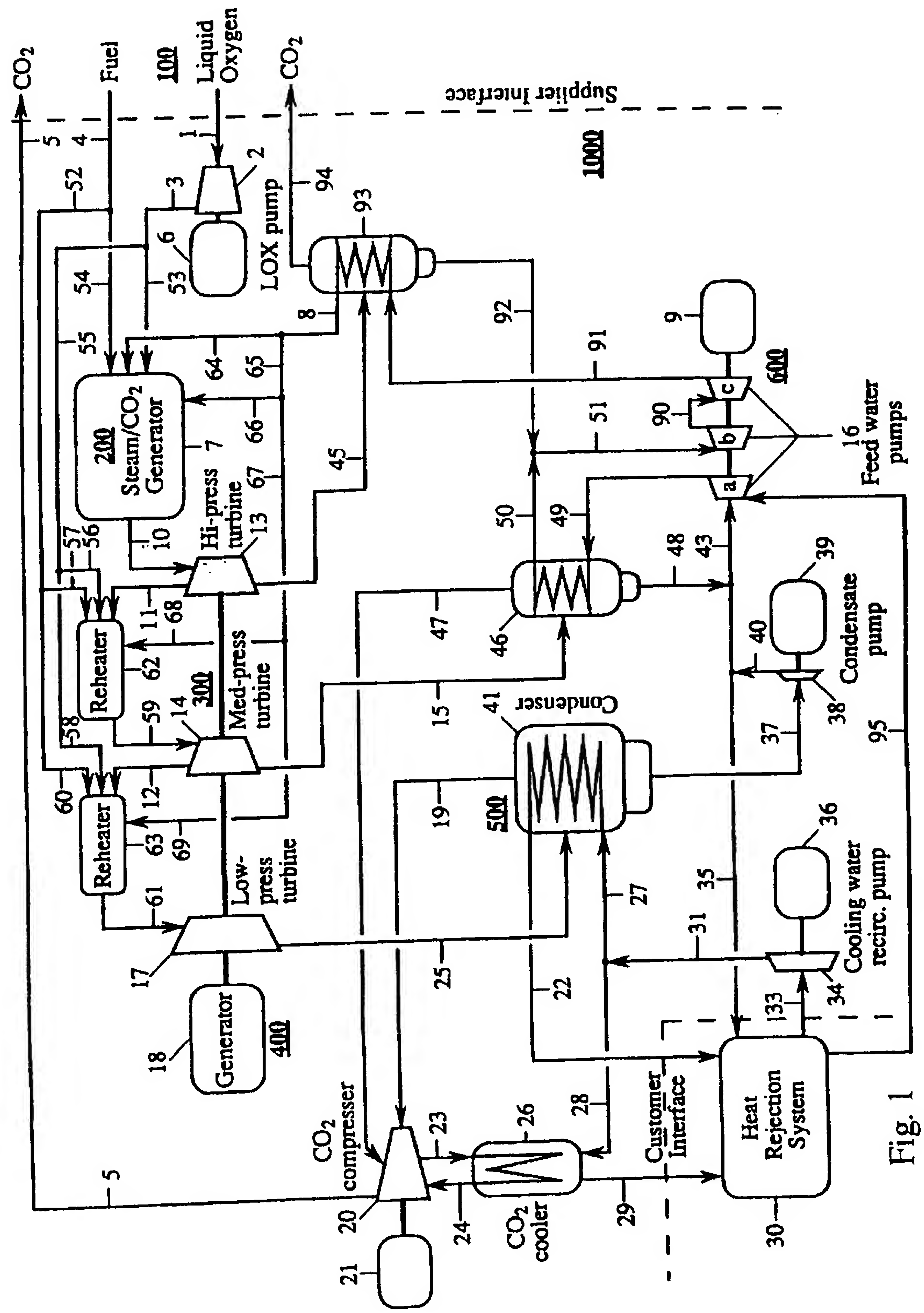
discharging high pressure, high temperature steam and carbon dioxide out of the combustion chamber.

Claim 40 - The method of claim 39 including the further step of controlling a temperature of combustion of the mixture of fuel and oxygen and a temperature of walls of the combustion chamber by the steps of:

providing fluid pathways which provide distribution circuitry for cooling water, the distribution circuitry provided proximate to the fuel and oxygen mixture when the mixture is ported into the combustion chamber,

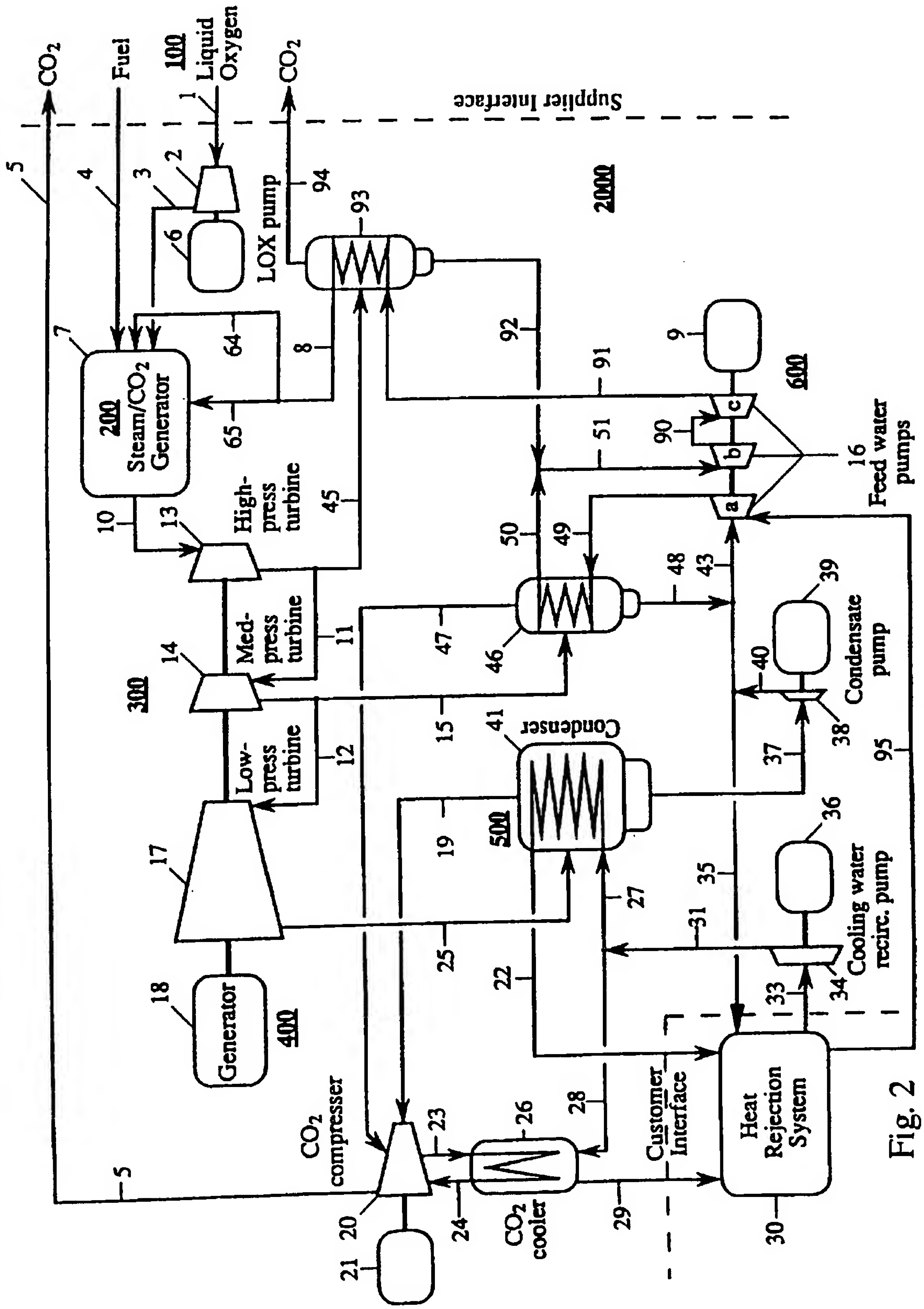
providing fluid pathways for cooling water in the walls of the combustion chamber, and

flowing water through the fluid pathways at a rate necessary to provide a desired temperature for the mixture of fuel and oxygen and for the walls of the combustion chamber.



CO₂
Fuel
100
Liquid Oxygen
CO₂
Supplier Interface
1000
LOX pump
200 Steam/CO₂ Generator
Hi-press turbine
Reheater
300
Med-press turbine
Reheater
Low-press turbine
Generator
400
Condenser
500
Condensate pump
Feed water pumps
600
Cooling water recirc. pump
Heat Rejection System
Customer Interface
CO₂ compresser
CO₂ cooler

Fig. 1



CO2
Fuel
100
Liquid Oxygen
CO2
Supplier Interface
LOX pump
2000
200
Steam/CO2 Generator
High-press turbine
Med-press turbine
Low-press turbine
300
Generator
400
Condenser
500
Condensate pump
Feed water pumps
600
Cooling water recirc. pump
CO2 compresser
CO2 cooler
Customer Interface
Heat Rejection System

Fig. 2

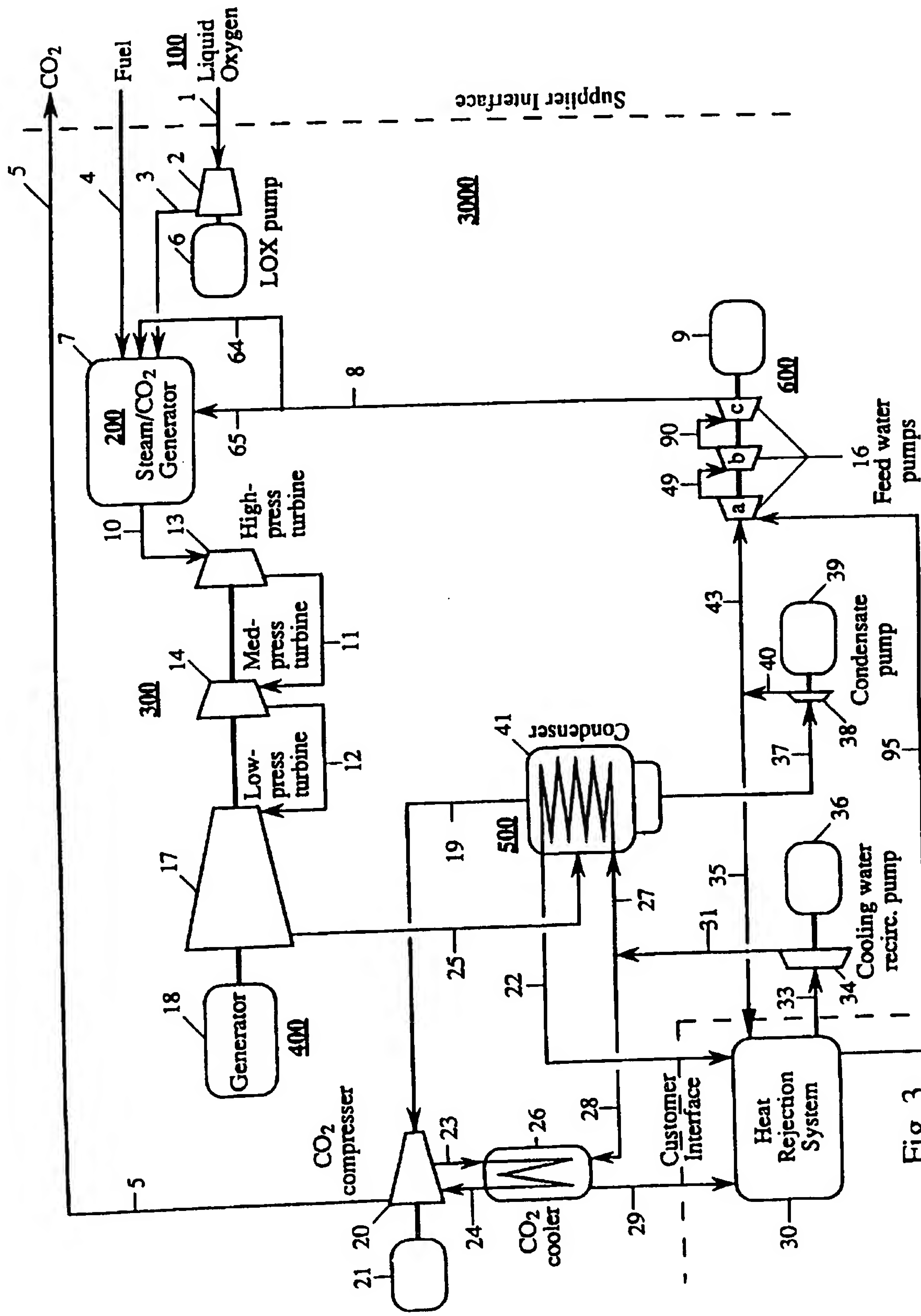

CO2
Fuel
100
Liquid Oxygen
Supplier Interface
3000
LOX pump
200
Steam/CO2 Generator
High-press turbine
Med-press turbine
Low-press turbine
300
Generator
400
Condenser
500
Condensate pump
Feed water pumps
600
Cooling water recirc. pump
CO2 compresser
CO2 cooler
Customer Interface
Heat Rejection System

Fig. 3

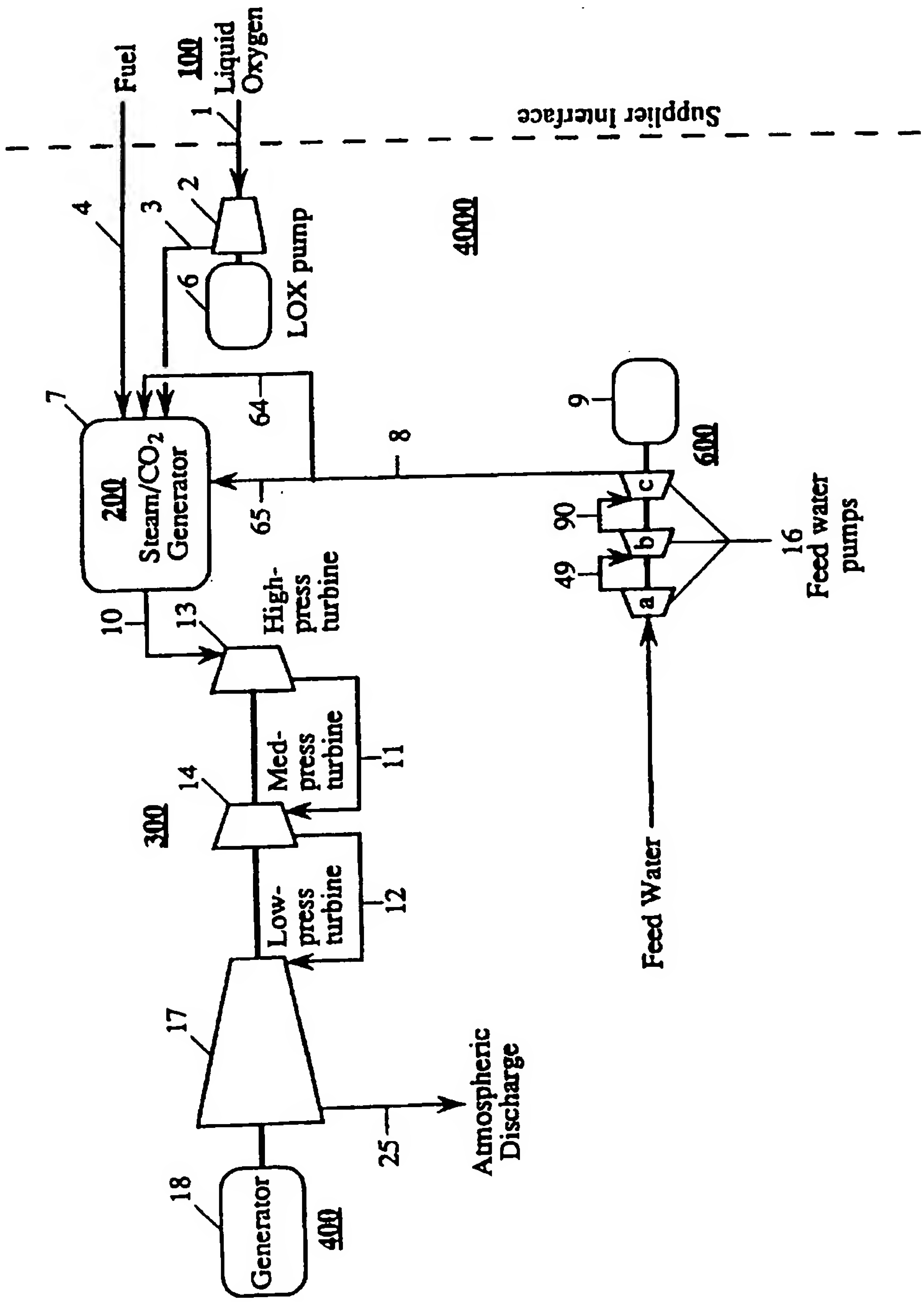

Fuel
100
Liquid Oxygen
1
Supplier Interface
2
3
4
6
LOX pump
4000
7
200
Steam/CO2 Generator
64
65
8
9
600
10
13
High-press turbine
Med-press turbine
11
14
300
Low-press turbine
12
17
18
Generator
400
25
Atmospheric Discharge
Feed Water
a
b
c
49
90
16
Feed water pumps

Fig. 4

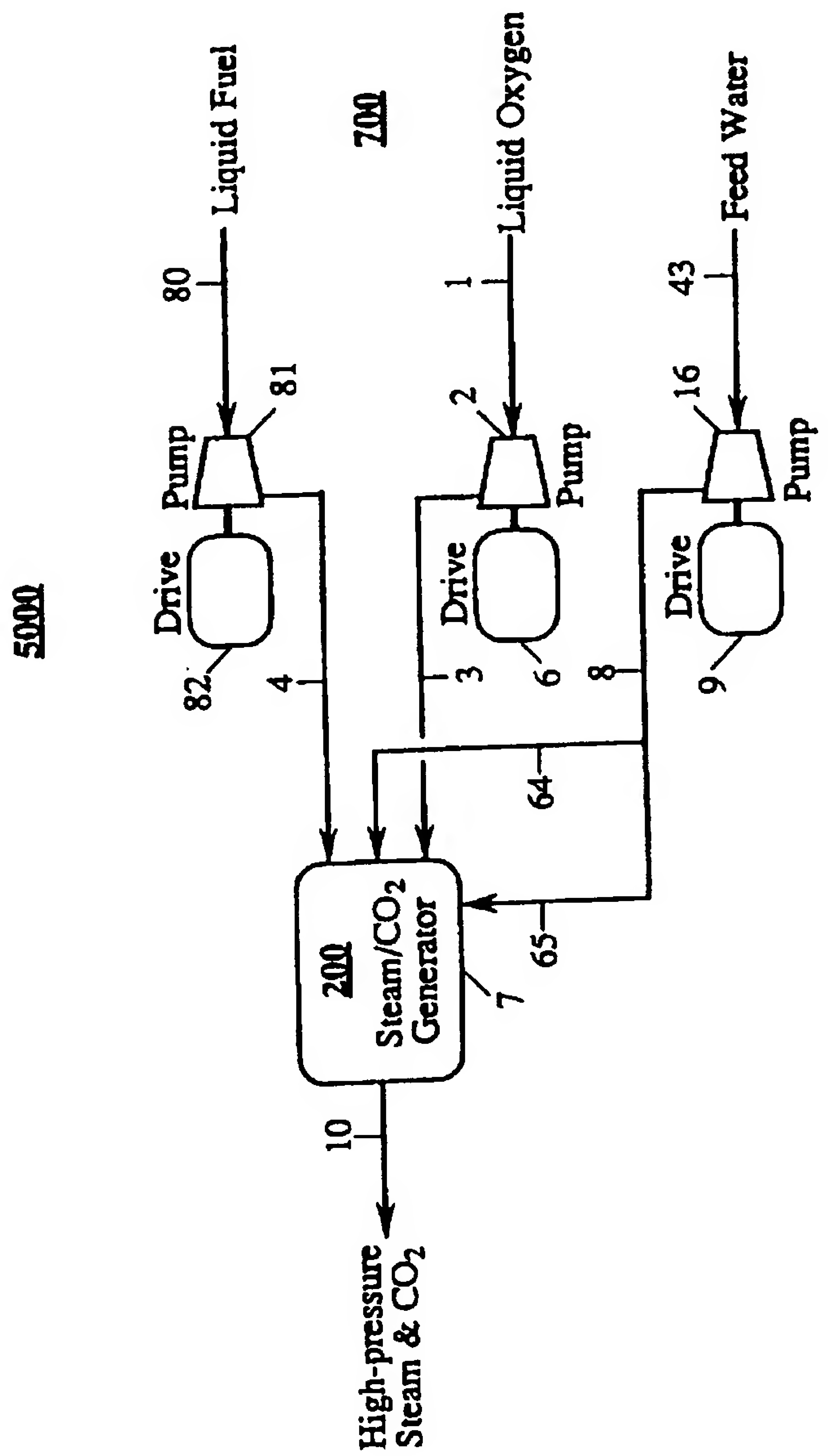

5000
Liquid Fuel
200
Liquid Oxygen
Feed Water
80
1
43
81
2
16
Pump
Pump
Pump
Drive
Drive
Drive
82
4
3
6
8
9
64
65
7
200
Steam/CO_2
Generator
10
High-pressure
Steam & CO_2

Fig. 5

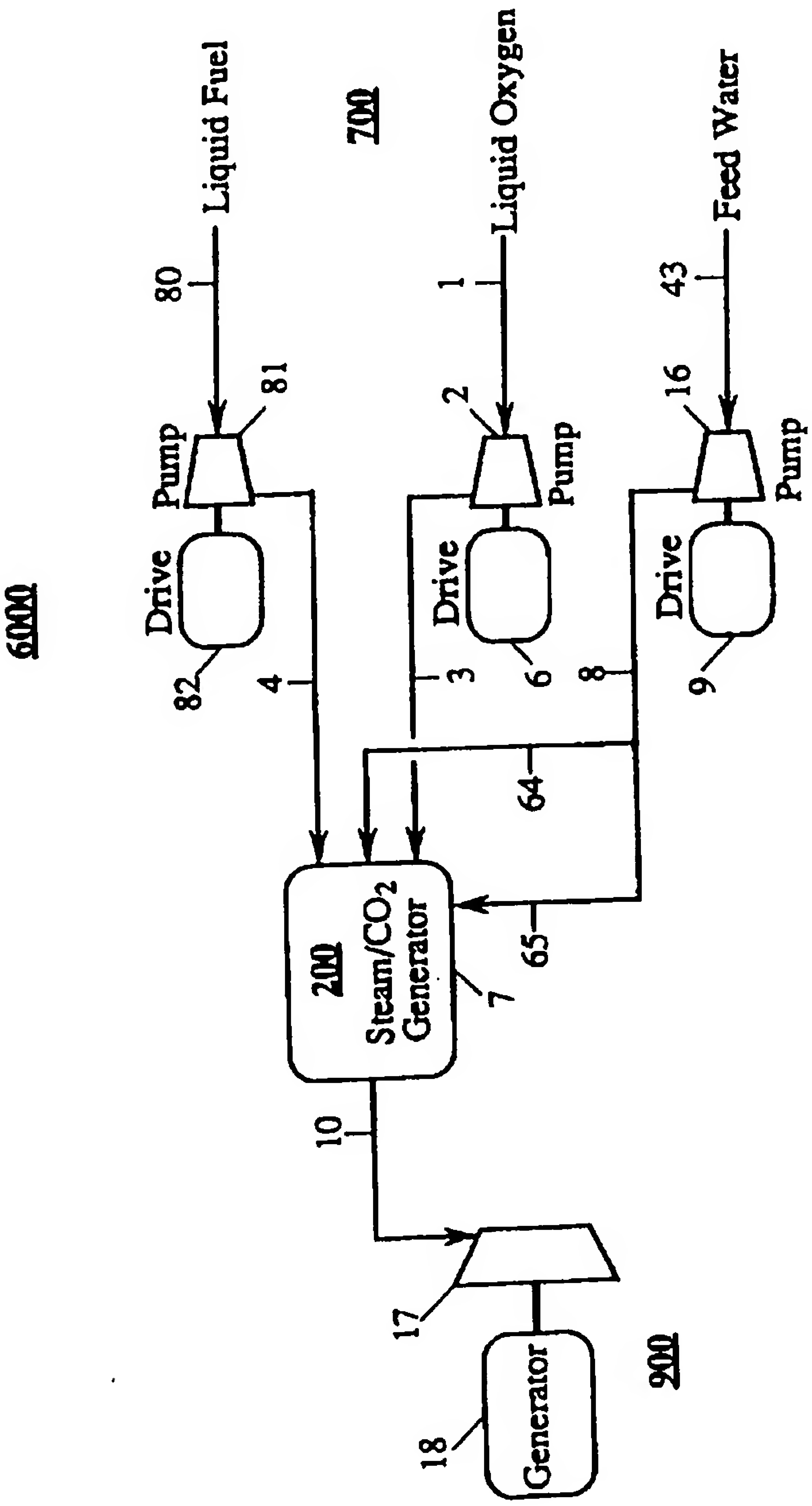

6000
Liquid Fuel
80
81
Pump
Drive
82
4
700
Liquid Oxygen
1
2
Pump
Drive
6
3
Feed Water
43
16
Pump
Drive
9
8
64
65
200
Steam/CO2 Generator
7
10
17
Generator
18
900

Fig. 6

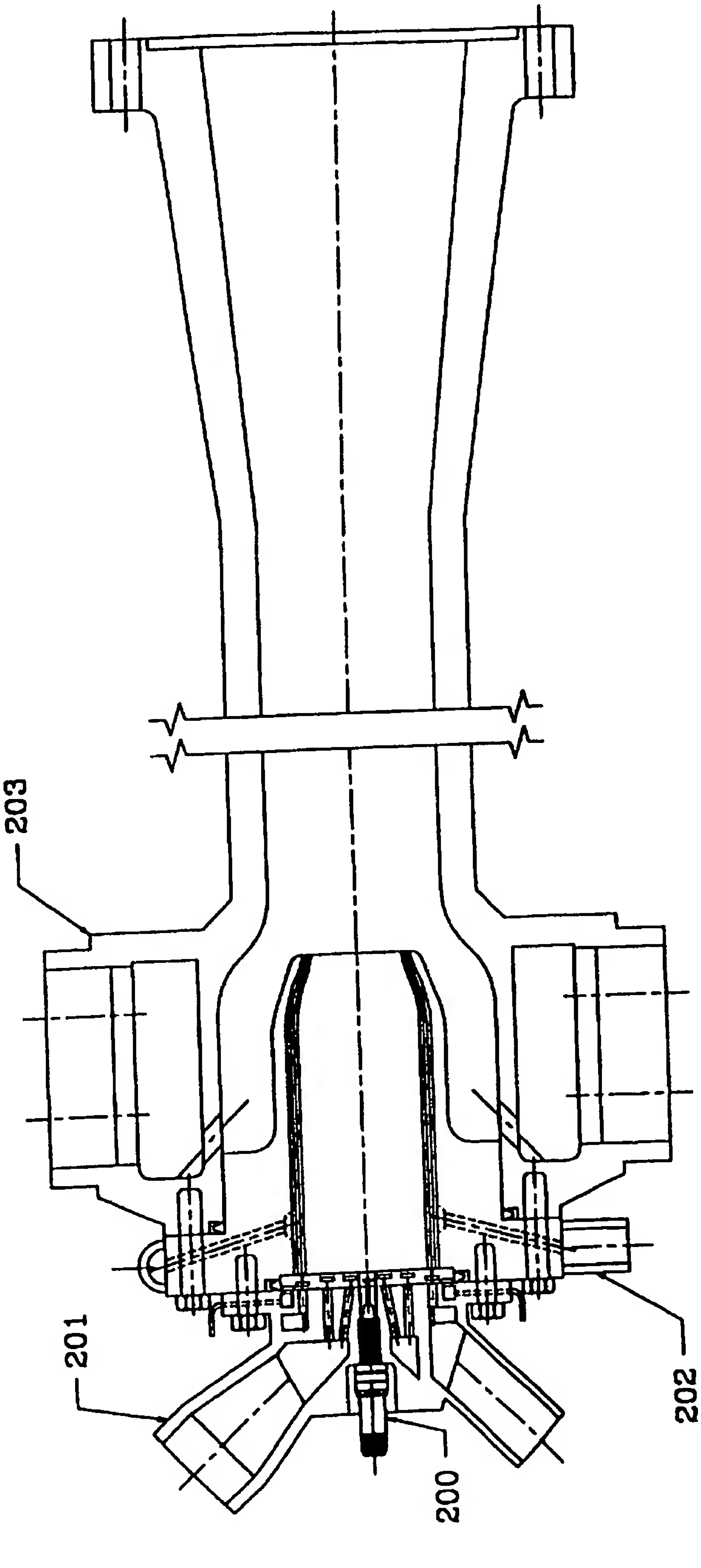


Fig. 7

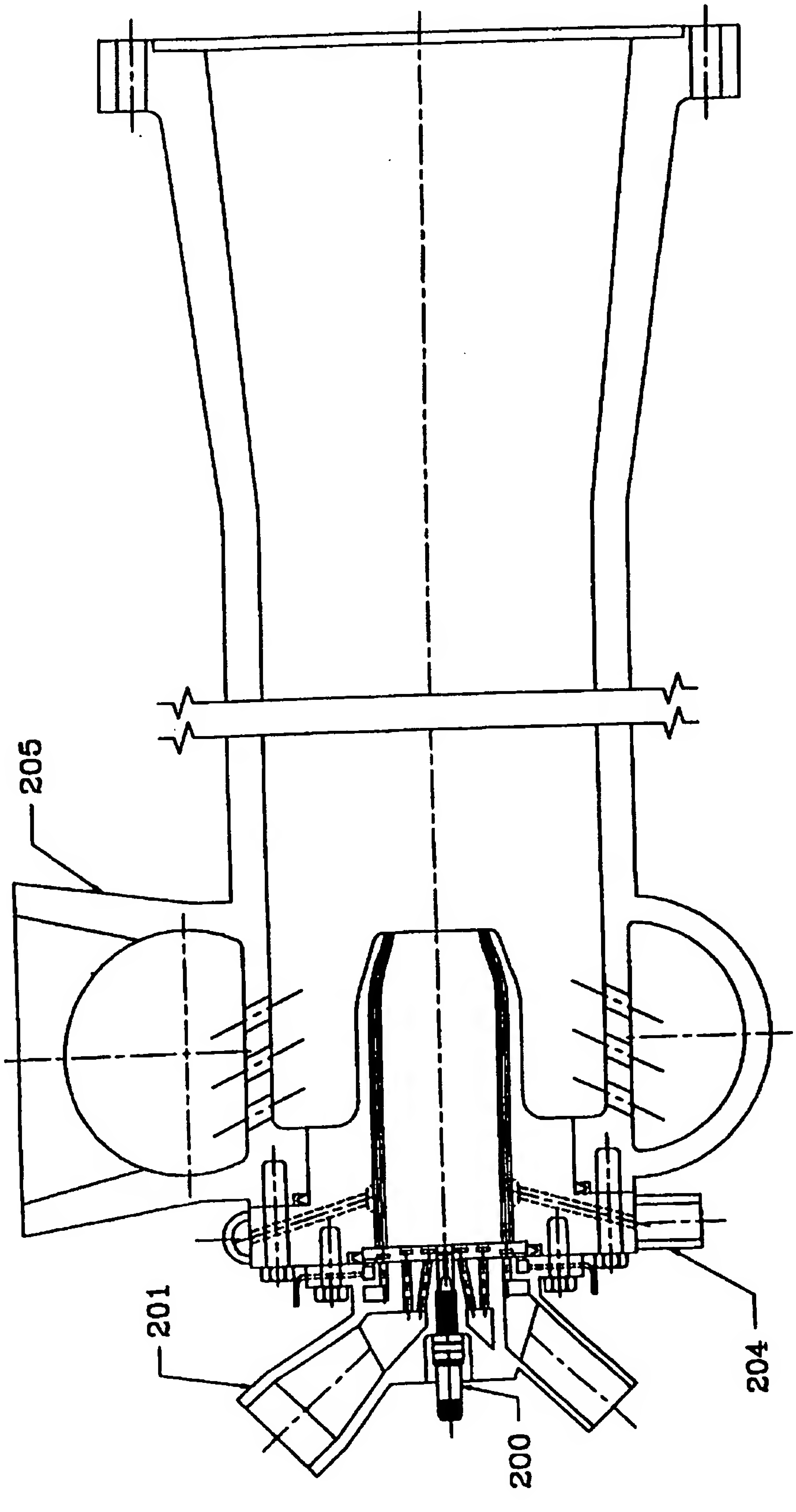


Fig. 8